4

Trends in Supply of Lithium Resources and Demand of the Resources for Automobiles

Hiroshi KAWAMOTO
Affiliated Fellow
Wakana TAMAKI
Researcher, Nanotechnology and Materials Research Unit

1 Introduction

A secondary battery contained in a lightweight and compact package is essential as the electric source to power hybrid vehicles (HVs) (that run on a combined system of a fossil fuel engine and an electric motor), plug-in HVs (PHVs) (for which the in-vehicle battery can be recharged using a commercial electric source), as well as electric vehicles (EVs). The development and introduction of such vehicles with secondary batteries and the subsequent substantial reduction of CO_2 have become a challenge of urgent concern.[1]

These vehicles with secondary batteries have entered widespread use more rapidly than expected. Therefore, demand for high-power, large-capacity lithium-ion batteries is expected to increase substantially by around 2030. A large amount of metallic lithium is required for electrode and electrolyte materials for secondary batteries. To meet rapidly increasing demand for metallic lithium, a stable supply of lithium raw materials is essential. Deposits of metallic lithium (a rare metal) are considered relatively abundant around the world. However, if demand for lithium for use in secondary batteries increases dramatically, the imbalance between supply and demand may become an issue depending on the resource policies of producing countries, their export restrictions, and the concentration of deposit areas. In Japan, the production of lithium minerals is slim to none. Japan is the world's largest importer of lithium raw materials and heavily depends on South American countries.

This article describes trends in the popularization of automobiles equipped with a secondary battery, estimates the amount of metallic lithium required for secondary batteries, and also introduces the current state of lithium supply and reserves, of resource nationalism in producing countries, and of the competition for lithium resources.

2 Future Demand Prospect

2-1 Trends in Diffusion Trend of Secondary Battery-equipped Automobiles and the Future Direction of the Batteries

Car manufacturers in Japan, China, the United States, Europe, South Korea, and other countries have begun introducing vehicles equipped with a secondary battery into the market and are announcing their expansion plans.[1,2] Lithium-ion batteries were not originally equipped in HVs, but it is expected that the introduction of lithium-ion batteries for HVs will accelerate and that all HVs, PHVs, and EVs will be equipped with lithium-ion batteries.

In the Action Plan for Achieving a Low-carbon Society (decided by the Cabinet in July 2008), the Japanese government sets a target of increasing the proportion of secondary battery-equipped vehicles (including HVs, PHVs, and EVs) to around 50% of domestic new car sales by 2020. Table 1 shows diffusion targets for HVs, PHVs, and EVs by 2020 and 2030 drawn up for the Next-Generation Vehicle Strategy by the Ministry of Economy, Trade and Industry (METI).[3] The popularization of automobiles equipped with a secondary battery will accelerate in Japan due to environmental policies.[4]

Among in-vehicle secondary batteries, the lithium-ion battery has the most excellent performance because of its superior characteristics in terms of power and energy density per unit weight or volume,[NOTE] and lithium-ion batteries are expected to be the mainstream power source until around 2030. Figure 1 illustrates the relationships between

Table 1: Diffusion targets for secondary battery-equipped automobiles by 2020 and 2030 (proportion of new car sales) set in the Next-Generation Vehicle Strategy by METI

<table>
<tr><th colspan="2" rowspan="2">Vehicle types</th><th colspan="4">Private-sector efforts</th><th colspan="4">Government targets</th></tr>
<tr><th colspan="2">FY 2020</th><th colspan="2">FY 2030</th><th colspan="2">FY 2020</th><th colspan="2">FY 2030</th></tr>
<tr><td rowspan="2">Secondary battery-equipped vehicles</td><td>HV</td><td>10~15%</td><td rowspan="2">Less than 20%</td><td>20~30%</td><td rowspan="2">30~40%</td><td>20~30%</td><td rowspan="2">20~50%</td><td>30~40%</td><td rowspan="2">50~70%</td></tr>
<tr><td>PHV EV</td><td>5~10%</td><td>10~20%</td><td>15~20%</td><td>20~30%</td></tr>
<tr><td colspan="2">Conventional vehicles</td><td colspan="2">80% or more</td><td colspan="2">60~70%</td><td colspan="2">50~80%</td><td colspan="2">30~50%</td></tr>
</table>

Prepared by the STFC based on Reference[3]

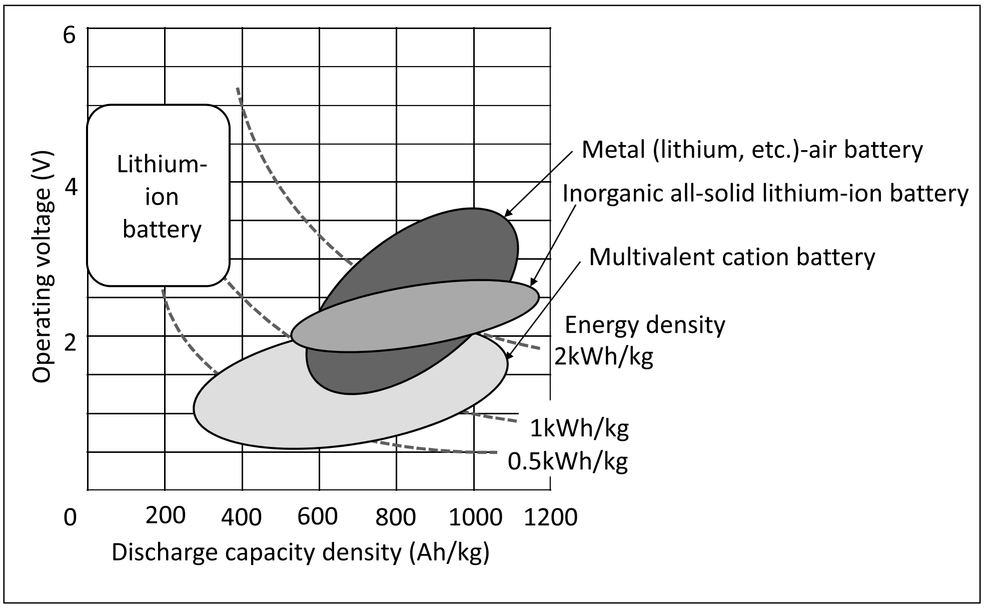


Figure 1: Relationships between operating voltage and discharge capacity density of secondary batteries in R&D processes

Reconstructed by SFTC based on Reference[5]

operating voltage and discharge capacity density.5] New secondary batteries (that have substantially enhanced power density and energy density) are also expected to be developed. Promising candidates include an all-solid (including an electrolyte) lithium-ion battery, a lithium-ion capacitor, a hybrid battery (which uses a lithium-ion battery and a lithium-ion capacitor), a metal-air battery, and a multivalent cation battery. Among all these types, an inorganic all-solid lithium-ion battery (composed of an electrode and an electrolyte) and a metal-air battery (where metallic lithium is used for the negative electrode) will most promisingly be able to achieve higher power and larger capacity.

A substantial amount of metallic lithium is required for both lithium-ion batteries (for which demand is expected to rise dramatically) and other promising batteries, and as such, demand for metallic lithium is expected to increase drastically. Additionally, large-capacity lithium secondary batteries will be used not only for automobiles but also for wider purposes.

[NOTE]

Power density designates the capacity of a battery to release energy in a short period of time, and is represented by the product of current and voltage (each per unit weight or unit volume of the battery). Energy density is represented by the product of discharge capacity density (discharge capacity per unit weight or unit volume) and operating voltage. A higher power density is required from the battery cells to secure enhanced driving performance for secondary battery-equipped vehicles. It is also required to enhance energy density in order to extend travel distance.[1]

2-2 Forecast on Demand of Lithium Resources for Automobiles

Metallic lithium is recyclable, so there was not much concern about the quantity as long as its uses were limited to portable electronics. However, compared to the quantity of metallic lithium required for electronics, demand for metallic lithium for secondary batteries (to be equipped in lithium battery-equipped automobiles like HVs, PHVs, and EVs) is incomparably larger.

According to a demand estimation of metallic lithium for secondary batteries for lithium battery-equipped automobiles (conducted by Illinois Institute of Technology), total sales of HVs and EVs will be 2.5 million in 2015 and 11,000tons of lithium carbonate will be required considering that 4.54kg of lithium carbonate is required per vehicle. Meanwhile, Sociedad Quimicay Minera de Chile (SQM), the world's largest lithium supplier in Chile, estimates that 20,000tons to 70,000tons will be required in 2020, and Chemetall (Chemetall GmbH), which is the world's third largest supplier and is based in Germany, estimates that 30,000tons to 60,000tons will be required in 2020. These are all optimistic estimates based on the idea that 200 or more years' worth of lithium reserves exist even if the number of HVs, PHVs, and EVs increases drastically.[6, 7] Incidentally, it takes 5.3kg of lithium carbonate to produce 1kg of metallic lithium.

The authors of this article, with the aim of facilitating environmental policies, estimated the amount of metallic lithium required to equip all automobiles in the world with lithium-ion secondary batteries. In 2010, the total number of automobiles in use worldwide will be about 900 million. For our estimation, we assumed that the amount of metallic lithium to be used would be 7kg per vehicle (secondary battery capacity: 5kWh) for HVs and PHVs, and 28kg per vehicle for EVs (secondary battery capacity: 20kWh). We also assumed that the content of metallic lithium in a lithium-ion battery would be 1.4kg/kWh. Based on these assumptions, Figure 2 illustrates, for three different ratios of EVs to HVs and PHVs, the amount of metallic lithium needed as a function of the percentage of HVs, PHVs, and EVs among automobiles worldwide. If we suppose that environmentally friendly automobiles make up 50% of all automobiles in use in the world (among which HVs and PHVs make up 50% and EVs make up 50%), about 7.9 million tons of metallic lithium will be necessary. As the next chapter describes, this amount almost equals the estimated amount of metallic lithium reserves. To maintain and strengthen Japan's competitiveness in this area, it is extremely important to secure lithium raw materials in a stable manner.

3 Supply of Lithium Resources within the grasp and Reserves

Rare metals are nonferrous metals used for various industrial purposes, each in small amounts. Their productions and supplies are small and their quantities are scarce. It is difficult to acquire these metals, from both economic and technological standpoints. Metallic lithium is one of the 31 rare metals but compared to other rare metals it is relatively abundant, with a Clarke number (the average content of an element

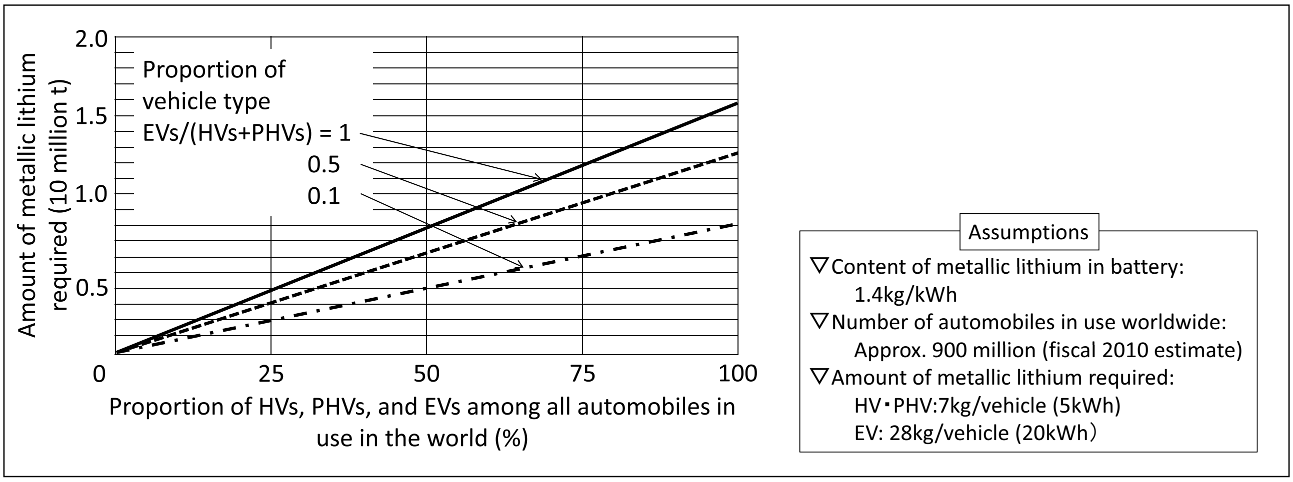
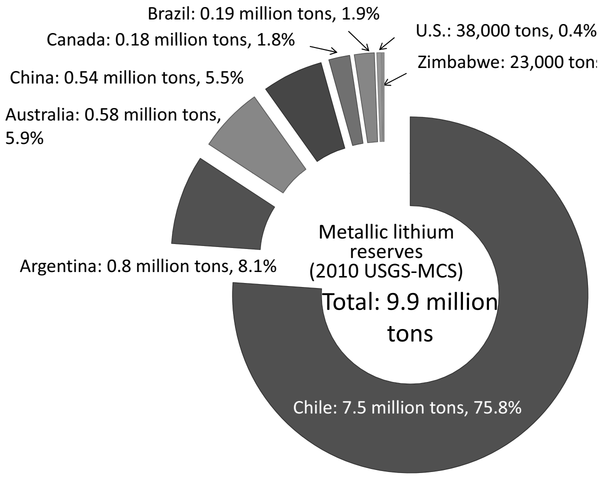


Figure 2: Amount of metallic lithium required if all automobiles in the world are equipped with lithium-ion secondary batteries.

Reconstructed by SFTC



Production / Producer	Production of metallic lithium raw materials by year (pure weight/ unit: ton)			
	FY 2005	FY 2006	FY 2007	FY 2008
Chile	8,270	8,200	11,100	12,000 (44%)
Australia	3,770	5,500	6,910	6,900 (25%)
China	2,820	2,820	3,010	3,500 (13%)
Argentina	1,980	2,900	3,000	3,200 (12%)
Canada	707	707	707	710 (3%)
Brazil	242	242	180	180 (1%)
Russia	2,200	2,200		(0%)
Zimbabwe	260	600	300	300 (1%)
Other	351	331	593	610 (2%)
Total	20,600	23,500	25,800	27,400 (100%)

(Note) Pure weight means pure metallic lithium contained in lithium ore.

Figure 3: World's reserves of metallic lithium raw materials and changes in the production amounts

Reconstructed by SFTC based on Reference[10-13]

in the Earth's crust) of 6×10^{-3} %. Therefore, metallic lithium was not considered a high-risk metal from the perspectives of supply and price.[8,9] However, there are growing concerns about risks arising from the fact that limited regions are producing lithium resources to cover most demand. There are also concerns about imbalance between demand-supplies and price fluctuations due to monopolistic supply.

3-1 Concentration of Lithium Resources in Certain Regions and State of Production on the Resources

Lithium resources are roughly divided into two categories: lithium resources from salt lakes (and other brine waters) and mines. As previously discussed, lithium is not a rare element. However, lithium resources that can be acquired efficiently and profitably are concentrated in some continental regions. Chile has the world's largest reserves of brine-source lithium, followed by Bolivia and Argentina; these three countries are considered to have about 80% of the world's reserves. The United States has the largest reserves of mine-source lithium, about 50% of the world's reserves, followed by Congo and Russia.[7] However, these are estimated reserves, and different organizations have very different estimates. Additionally, these estimates will be continuously updated.

Figure 3 illustrates the world's reserves of metallic lithium raw materials based on the Mineral Commodity Summaries (MCS) issued in January 2010 by the United States Geological Survey (USGS).[10,12] It also illustrates changes in the production of metallic lithium raw materials based on Mineral Resource Material Flow 2009 by the Japan Oil, Gas and Metals National Corporation (JOGMEC).[13] It is said that the world's reserves of metallic lithium amount to 9.9 million tons, of which Chile has 7.5 million tons (about 76%). The second largest reserves holder, Argentina, is also in South America.

Recently, a lithium-rich salt lake was found in Bolivia (which is next to Chile) and it likely has one of the world's largest reserves. There are claims that this lake, Uyuni salt lake, has 50% of the world's lithium reserves, and the quality has been investigated. The amount of Bolivia's reserves is not clear at this point and is not calculated into the world's reserves. However, it is apparent that lithium resources will be more concentrated in South America.

3-2 State of Distribution on Lithium Raw Materials

The form of lithium raw materials in distribution varies: lithium mica and other pegmatite ores, spodumene, petalite, lithium carbonate, lithium hydroxide, and metallic lithium. A great amount of lithium is distributed in the form of lithium carbonate. However, only the amount of lithium hydroxide in distribution (through imports and exports) can be verified according to trade statistics. The amount of lithium in other forms has not been verified and is estimated through interviews from a demand-side perspective.

Figure 4: Changes in trading prices of lithium hydroxide calculated from the UN comtrade DB

Prepared by STFC based on the data from Reference[14]

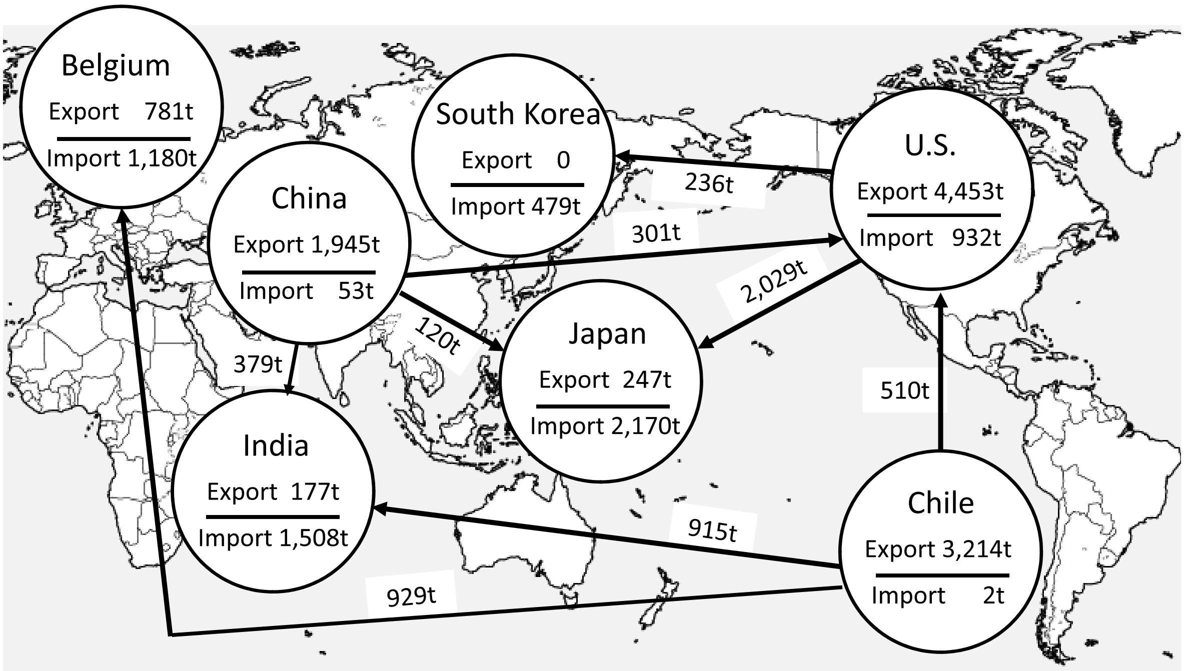


Figure 5: Major international distribution volume of lithium hydroxide based on trading statistics (2009)

Prepared by STFC based on the data from Reference[14]

As figure 4 illustrates, the world's production of metallic lithium raw materials was about 27,400 tons in 2008. However, in 2009, it is estimated that Chile, the world's largest exporter, exported 25,000 tons of lithium carbonate. About 50% of Chile's total exports of lithium carbonate were split between Japan, South Korea, and China, with about 25% of the total going to Japan. Its exports to South Korea have also been increasing in recent years.[12]

Major lithium suppliers include SQM, Sons of Gwalia Ltd. (Australia), Chemetall, GEA Group AG (Germany), FMC Lithium (U.S.), Potash Corp of Saskatchewan Inc. (Canada), and Yara International ASA (Norway). However, the top three suppliers (SQM, Chemetall, and FMC Lithium) hold about a 70% share of the world's lithium raw materials, and they have a strong ability to control the prices. In particular, SQM is the price leader. For instance, SQM suddenly announced a price reduction at the end of 2009, when demand for lithium raw materials increased rapidly and the price dramatically went up, and as a result, the balance between demand and supply was greatly disrupted. The price was reduced in the name of creating new demand. However, some speculate that it was done to shake down small mining companies. As of 2010, it may be no exaggeration to say that SQM determines the prices of lithium raw materials in distribution.

Lithium raw materials are not listed at the London Metal Exchange (LME), a worldwide non-ferrous metals market, where seven non-ferrous (including copper, nickel, and lead) metals are listed. Therefore, there are no publicized world standard prices for lithium raw materials. The prices for lithium raw materials are either the prices asked by SQM or prices negotiated between mining companies and trading firms. In Japan, purchase prices (in the first/second half year or each quarter) announced by trading firms or lithium carbonate prices in the Chinese market are the price indicators. The prices have not decreased at all since June 2009, and they have been kept high through August 2010. The prices have been continuing to rise.

Changes in export and import prices based on UN comtrade DB (United Nations Commodity Trade Statistics Database) illustrate internationally-comparable price indicators (follow-up data).[14] Figure 4 and 5 illustrate changes in export and import prices of lithium hydroxide calculated from the UN comtrade DB. As discussed earlier, among lithium raw materials in distribution, only the amount of lithium hydroxide can be verified. Figure 4 indicates that prices of lithium resources have been increasing in general since 2005. Figure 5 illustrates that Japan imports most lithium hydroxide from the United States, and not much from Chile or China. Each country depends heavily on its certain trading partners and their trade volumes also vary significantly.

Even if lithium reserves are abundant, supply instability will continue to exist due to the concentration of resources in certain regions, an oligopoly of a few suppliers, and the absence of a price indicator. The production of automobiles (equipped with secondary batteries that use a lot of metallic lithium) has been increasing, and there are concerns about a shortage of supply due to a drastic demand increase, and these concerns make price forecast even more uncertain. As the number of automobiles equipped with a secondary battery increases around the world, a gradual increase of lithium production

3-3 Japan's Import Volume of Lithium Raw Materials

Japan was the world's largest importer of lithium raw materials in 2008 and 2009, and its import prices are always higher than the world average.

Table 2 illustrates changes in Japan's import volume of lithium raw materials.[13,15] Japan mostly relies on Chile for lithium carbonate, a major lithium raw material, and also imports lithium hydroxide and metallic lithium from the United States.

Japan's import prices of lithium raw materials are on the decline. However, it is speculated that, by lowering prices of lithium raw materials, the supply side is trying to prevent Japanese companies from investing heavily in new lithium development projects. Demand for lithium raw materials is likely to increase rapidly, and as such, to stably procure the materials, it is essential to reduce the country's heavy reliance on South America as well as to develop other resources in advance of the demand.

Table 2: Changes in Japan's import volume of lithium raw materials

Lithium raw materials	Import volume by fiscal year (ton) based on Trade Statistics of Japan				Major import trading partners (FY 2008)	Major uses
	FY 2005	FY 2006	FY 2007	FY 2008		
Lithium carbonate	10,001	14,521	13,553	13,194	Chile 83% U.S. 9% China 5%	Electrode/electrolyte for secondary battery Additive for heat-resistant glass
Lithium hydroxide	1,503	2,138	2,747	2,408	U.S. 92% China 5% Chile 4%	Electrode/electrolyte for secondary battery (High grade lithium materials) Additive for grease
Metallic lithium	162	153	142	134	U.S. 54% China 32% Russia 11%	Electrode for primary battery Catalyst for synthetic rubber Metal-reducing agent

Prepared by STFC based on data from Reference[13,15]

4 Trends in Lithium Resource Policies by Country and State of Competition for the Resource Acquisition

Lithium resources are relatively abundant; however, as demand for metallic lithium is expected to rise dramatically, there is a concern about supply shortage due to supply instability as a result of the concentration of deposit areas. There is also a concern about price rises due to mining and export restrictions imposed by producing countries and due to resource nationalism.[16] Japan is the world's largest lithium importer and needs to closely watch resource policies of lithium producing countries as well as trends in monopolistic producing companies and the latest changes in prices of lithium raw materials.

4-1 Trends in Chile's Resource Policy

Chile is currently considered to have the world's largest reserves of lithium resources and is also the largest producer of lithium resources. Government offices, the institute of mining and metallurgy, and other government-related organizations established a lithium committee to examine lithium resource policy from the perspectives of technology, legal systems, and the private sector's entry into the market.

In August 2010, Chilean Ministry of Mining, Sociedad Nacional de Mineria (SONAMI), SQM, and SCL (Chemetall's subsidiary company) held a seminar on the liberalization of lithium resource mining. At the seminar, the minister of mining, senators, other government officials, SQM, SCL, Ford, and other companies in related industries exchanged views, and private companies strongly opposed the Chilean government's proposal concerning lithium resource mining restrictions. The minister of mining stated that the government's role was to promote public policy to provide incentives, and the senators stated that a new organization needed to be established to facilitate the liberalization of lithium resource mining and promote research and development of lithium-related products. Views on the liberalization of lithium resource mining remained mostly conservative: that it should be considered within the framework of the constitution in order to protect society's interest. Some senators said that building connections between the government and companies would be in the country's interest. SQM argued that there was no reason to make lithium a strategic mineral, as there were no other countries (except Chile) that were trying to impose mining restrictions, and that the automobile industry would not trust Chile's lithium market if such restrictions were imposed. Chemetall also made a similar statement to the media, saying that the company would expand its business outside Chile if the Chilean government continued to restrict lithium resource mining.[17]

4-2 Trends in China's Lithium Resource Acquisition

China's lithium reserves are considered to be the world's fourth largest. It is estimated that in 2009, China produced 1,000 tons of metallic lithium, 30,000 tons of lithium carbonate and other materials, and 20,000 tons of positive electrode materials for lithium-ion batteries.[18]

In July 2010, the China Nonferrous Metals Industry Association requested the government to establish a branch for the lithium industry. There are about 50 metallic lithium and lithium product companies in China, and 40 of them favor the establishment of the lithium industry branch.

China has been actively investing in its domestic infrastructure in order to stably secure raw materials. Lithium carbonate production sites have recently been built at Zhabuye Salt Lake in Tibet and Qaidam Basin in Qinghai. Major lithium carbonate producing companies are Tibetan Mining Industry, Citic Guoan MGL, Western Mining Group Co., Ltd., and Qinghai Salt Lake Industry Group Co., Ltd. At the beginning of 2007, Qinghai Citic Guo'an Science & Technology Development Co., Ltd. invested in a lithium carbonate project at Western Taiji'nai'er Lake in Qaidam Basin.[19] Qaidam Basin is rich in mineral resources including potassium, sodium, magnesium, lithium, and boron. In particular, the reserves of lithium chloride are about 14 million tons, 83% of the total reserves in China.

4-3 Trends in South Korea's Lithium Resource Acquisition

At the end of 2009, the South Korean government released its comprehensive policy for the development of the rare metal industry. Demand for ten rare metals, including lithium, is rising in South Korea, and therefore, the country will try to increase its self-sufficiency rate from the current 12% in 2009 to 80% by 2018 through recycling and securing rights. South Korea will invest about 22.2 billion yen by 2018 to develop extraction technology for the ten rare metals, as well as recycling-related new technology.

Competition is intensifying between Japan, France, China, and South Korea to secure the right to develop the salt lake in Bolivia, which likely has the world's largest reserves. In particular, South Korea is very committed. In August 2010, the South Korean President met the Bolivian President, who was visiting South Korea, and the state-run mineral resources corporations in the two countries concluded a memorandum of understanding on research and development and industrialization of the lithium reserves in Bolivia. The memorandum proposes the establishment of a joint research group to develop lithium reserves in Uyuni Lake. It also includes that a consortium of South Korean companies will propose a project to industrialize lithium-ion batteries and participate in a pilot plant in Bolivia.[20,21]

4-4 Trends in Japan's Lithium Resource Acquisition

According to the Basic Energy Plan by METI, Japan also aims to increase its self-sufficiency rate of lithium and other rare metals by over 50% by 2030 through recycling and securing rights. The plan proposes joint efforts of the public and private sectors to acquire resources.[22] It is important to secure mining rights to mineral resources in producing countries in order to stabilize the supply of lithium resources at low cost. Japan is completely dependent on imports for lithium resources, and as such, it is essential to mitigate risk by reducing heavy dependence on South America and by trading with a greater variety of countries.

Therefore, an industry-government-academia consortium (including METI, JOGMEC, The National Institute of Advanced Industrial Science and Technology (AIST), Kitakyushu University, and Mitsubishi Corporation) took the lead over other countries by acquiring the right to participate in lithium extraction experiments in Bolivia. At the beginning of 2011, the consortium plans to begin extraction experiments at a center near Uyuni Lake and to continue to experiment for about one and a half years. The consortium, during the process of finding extraction points and developing technology to make high-grade lithium resources, will also train local engineers, construct electricity supply facilities, and build other infrastructures for resources development.[23] At Uyuni Lake in 2008 and 2009, JOGMEC provided technological support to Mitsubishi Corporation (which developed a lithium recovery system from brine water) and Sumitomo Corporation (which developed a selective separation method between lithium and boron from brine water). These projects were successful in using ion-exchange resin to acquire concentrated lithium resources from brine water. However, Japan falls behind South Korea and China in terms of earning rights of deposits.

Recently, it was reported that Japan and Mongolia would jointly develop rare earth elements and mineral resources, including lithium resources.[24] There is a salt lake in Western Mongolia that is considered to be rich in metallic lithium. In fiscal 2011, JOGMEC and AIST will work with the government-related organizations of Mongolia to research lithium content in the lake and investigate a prospect to refine the resources into lithium carbonate. The joint project aims for the private sector to develop businesses in three to four years. If it is confirmed that the production of raw lithium carbonate materials and the economic efficiency thereof can be realized, the joint development project will contribute to the diversification of Japan's trading partners for lithium resources.

In November 2009, JOGMEC gained a 40% interest in the lithium deposit in Nevada, United States. JOGMEC will invest in research in cooperation with American Lithium Minerals Inc., an exploration company, and aims to produce 10,000 tons of lithium raw materials from the deposit. The volume will equal about 10% of the world's production.[25]

Japanese trading firms are active in acquiring mining rights for lithium resources. Mitsubishi Corporation signed a long-term sales agreement with Galaxy Resources Limited in Australia, aiming to sell 5,000 tons of lithium carbonate in five years from now.[26] In January 2010, Toyota Tsusho Corporation and Orocobre Limited of Australia signed an agreement under which Toyota Tsusho would participate in the mining project being conducted by Orocobre in Argentina and would conduct joint commercialization research with Orocobre.[27] They will investigate resources in Salar de Olaroz, in the northwestern part of Argentina, close to the border of Chile. Around 2014, they plan to begin mining 15,000 tons of lithium resources per year. In July 2010, Itochu Corporation invested in Simbol Mining Corp, a resources development company (producing lithium raw materials) in the United States and acquired the right to sell lithium raw materials in Japan, China, and other parts of Asia. Itochu announced that the company would begin full-fledged production of metallic lithium raw materials around 2015 (about 16,000 tons, which is about 30% of the total demand for lithium raw materials in Japan).[28] Additionally, Mitsui & Co., Ltd. signed an agreement with Canada Lithium Corp (which aims to begin production of lithium raw materials in 2012) and acquired an exclusive distributorship in Japan, South Korea, and China.[29]

5 Direction for Medium- to Long-term Research and Development

5-1 Recovery Process Technology for Lithium Resources

5-1-1 Solving Issues Surrounding the Production Process of Lithium Carbonate Raw Materials

Metallic lithium is chemically active, so in most cases, lithium raw materials are produced, maintained, and transported in the form of lithium carbonate (Li_2CO_3), which is used to make lithium compounds for secondary batteries. Japan is the world's largest importer of lithium resources, and therefore, it is essential to work with companies in lithium producing countries to establish a low-cost lithium carbonate production business and to secure stable import volume by using Japan's strength in technology.

Currently, most lithium raw materials are produced from brine water in salt lakes. When a lake is enclosed by land and has a higher concentration of salt than a normal freshwater lake, it is called a salt lake, and the highly concentrated salt water is called brine water. The lithium concentrations in the brine water of the salt lakes in Chile, Argentina, and Bolivia are only between 0.04 and 0.16%. However, the production process for brine-water lithium costs 30% to 50% less than the production process of mining, selecting, refining, and carbonating lithium contained in ores.[11]

Figure 6 illustrates a major production process for lithium carbonate raw materials from brine water.[11,30] This is an evaporative concentration/refinement method, where, during the concentration process, brine water is concentrated by the sun in an evaporation pond, and sodium, potassium, and magnesium chloride (NaCl, KCl, and $MgCl_2$) are crystallized and removed to acquire concentrated lithium chloride (LiCl). During the refining process, calcium carbonate (CaO) is added to LiCl to remove

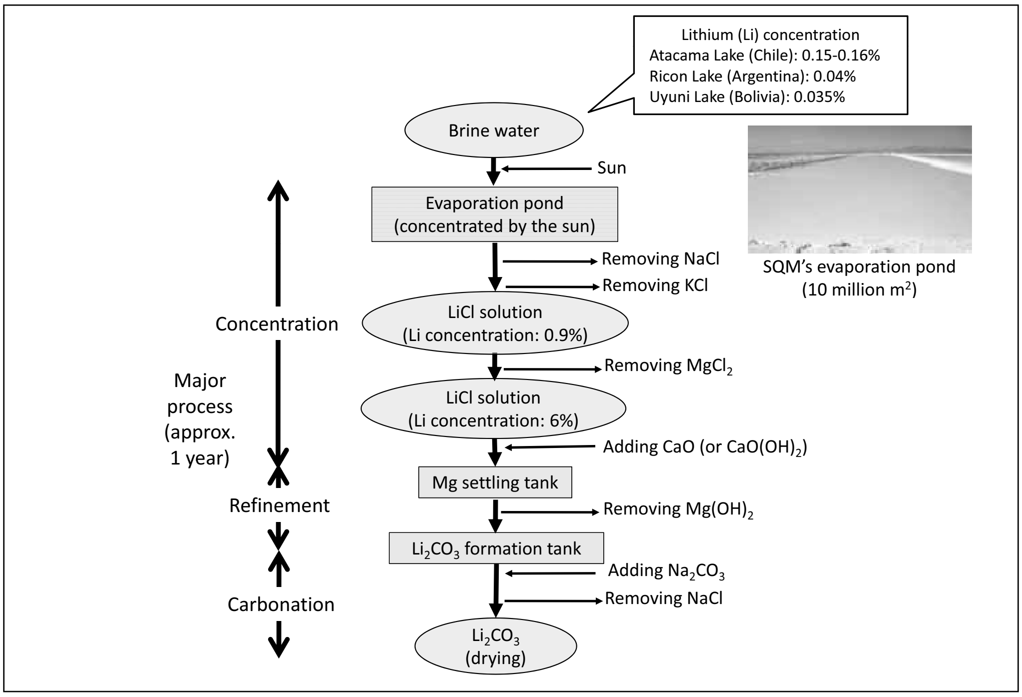


Figure 6: A major production process for lithium carbonate raw materials form brine water

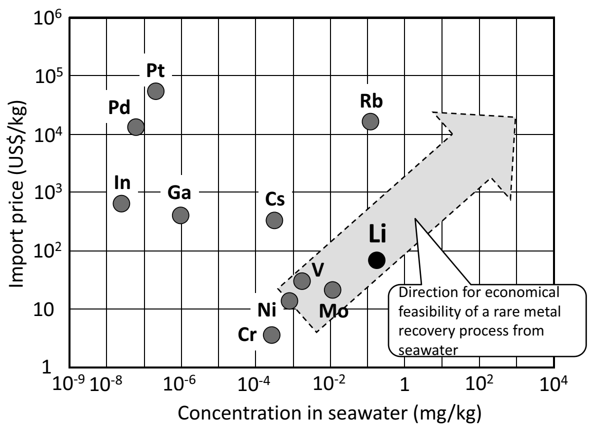
Prepared by STFC based on Reference[11,30] magnesium hydroxide, and sodium carbonate (Na_2CO_3) is used to acquire lithium carbonate. In the production process of brine-water lithium resources, the sun is used to concentrate the water, and therefore the whole production process takes about one year, which is an issue. To flexibly respond to demand of lithium for secondary batteries and supply materials accordingly, it is necessary to develop technology to substantially reduce the time required for raw material production process.

5-1-2 Prospect of a Process for Lithium Recovery from Seawater

Lithium also exists in seawater, though the proportion is small, and the concentration is 0.1 to 0.2mg/l. Globally, there is a substantial amount of metallic lithium (230 billion tons) in seawater. Figure 7 illustrates concentrations of major rare metals in seawater and the import prices of those raw materials.[10,13,31] It allows us to consider the economic efficiency of rare metal recovery from seawater. Generally speaking, it is economically feasible to recover rare metals from seawater when their concentration levels are high even if their market prices are relatively low. Metallic lithium falls near the edge of this domain of economical feasibilty.[31,32] In the long term, if new processes make it possible to separate highly-concentrated lithium compounds from seawater without using a lot of energy, it will be possible to acquire lithium resources from seawater at an industrial level.

Figure 8 illustrates an outline of an absorption process of metallic lithium from seawater (under the process of research and development).[32] To selectively absorb and recover metallic lithium from a dilute aqueous solution (seawater) containing metallic lithium, manganese oxide absorbents are used because they have high lithium selectivity. Manganese oxide absorbents are also used for the positive electrodes of lithium-ion batteries. The amount of lithium absorbed in this process equals the amount of metallic lithium contained in low-quality ores. The Institute of Ocean Energy at Saga University began operating the world's first—but small—lab aiming for practical lithium production from seawater and succeeded in acquiring about 30g of lithium chloride from 140,000 liters of seawater in one month.[33] However, setting conditions for preparing and operating the process to desorb absorbed metallic lithium in an acid solution is troublesome, and as such, it is difficult to treat a large amount of metallic lithium using the current recovery method. It is essential to reduce production time and cost. Additionally, there is a process where metallic lithium is separated, concentrated, and refined through solvent extraction. However, this lithium recovery process is considered less likely to be of practical use because it requires multiple rounds of extraction using an expensive solvent and high energy consumption.

Additionally, there is a high concentration process whereby an inorganic porous membrane is used as a separation membrane. A separation membrane, taking advantage of the different sizes of the materials (that need to be separated and refined), absorbs and selectively allows the passage of materials. Figure 9 illustrates the concept of a nanoporous structure-based lithium-ion separation membrane and cell. Porous membranes have been researched and developed using materials of various sizes including the nano scale. Taking advantage of ceramics' superior resistance to heat and chemicals, R&D efforts have been focused on nanoporous ceramic separation membranes, where microscopic pores (at a sub-nanometer scale) are placed in a continuous and regular manner.[34] If



(Note) The rare metal prices are raw material import prices taken from "Mineral Resources Material Flow 2009" (issued by JOGMEC[13]), which are based on Trade Statistics of Japan (fiscal 2008) and USGS-MCS.[10] The concentrations of rare metals in seawater are based on data in Reference.[31] The price of lithium equals the import price of metallic lithium raw materials. The prices of other rare metals (excluding platinum, palladium, gallium, and indium) equal the import prices of raw materials such as nickel oxide, chrome oxide, molybdic anhydride, vanadium pentoxide, and cesium compound.

Figure 7: Relationships between concentrations of major rare metals in seawater and their raw material import prices

Prepared by STFC

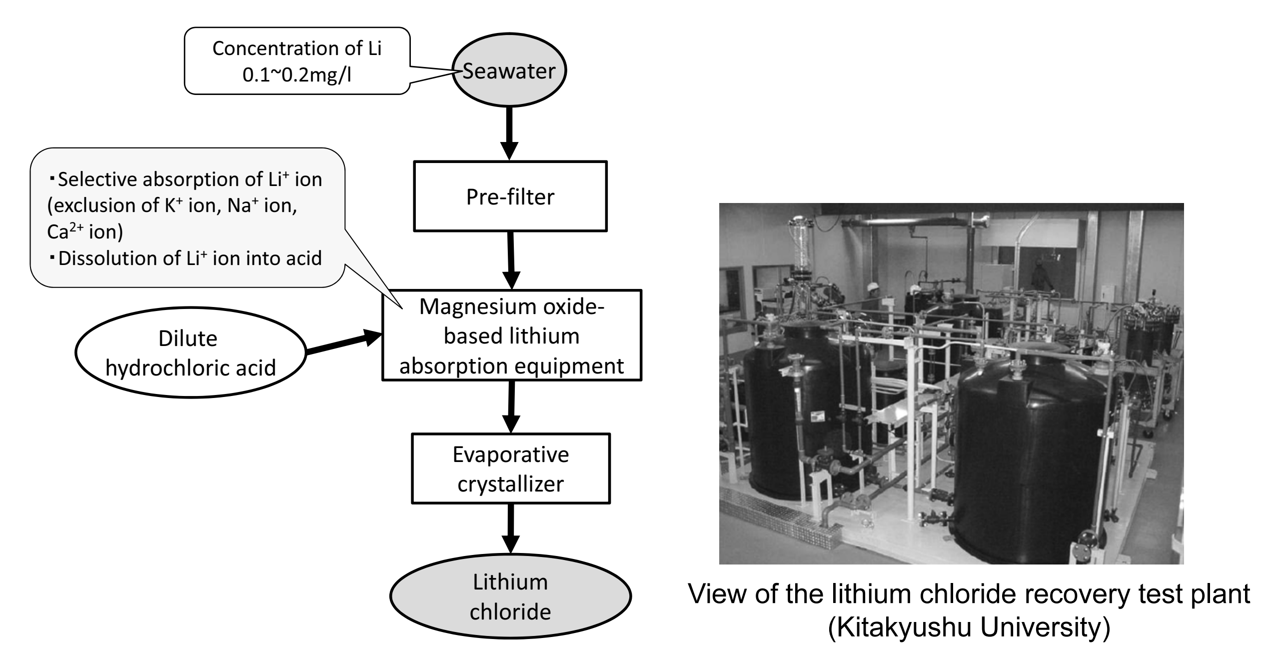


Figure 8: Overview of a process to absorb metallic lithium from seawater

Prepared by STFC based on Reference[32]

separation membranes can be structured into cells (using a material that can absorb lithium compound) so that the membranes can separate lithium ions from potassium, calcium, and sodium ions (which are larger than lithium ions), it will be possible to have a system where hardly any energy is used for absorption and separation. To accomplish this, nanoporous separation membranes, like a manganese oxide-based absorbent, are required both to recognize the size of lithium ion and absorb the ion as well as to permeate and separate the ion.

5-2 Research and Development of Metallic Lithium-free Secondary Batteries

METI's Study Group on Next-Generation Vehicle Strategy proposes the development of rare-metal-free secondary batteries in the long term.[3] NEDO's 2008 Roadmap for the Development of Next Generation Automotive Battery Technology lists innovative candidates for secondary batteries, such as a metal-air battery and a multivalent cation battery, to replace metallic-lithium-based secondary batteries.[5] In the long term, it is desirable to research and develop these innovative batteries.

Figure 10 illustrates the electricity-generation mechanisms of a lithium-free zinc-air battery and of a multivalent cation battery with a magnesium negative electrode. In a metal-air battery, the material volume of the positive electrode can be characteristically smaller, enabling the battery to become light and compact. Zinc, aluminum, and other metals may

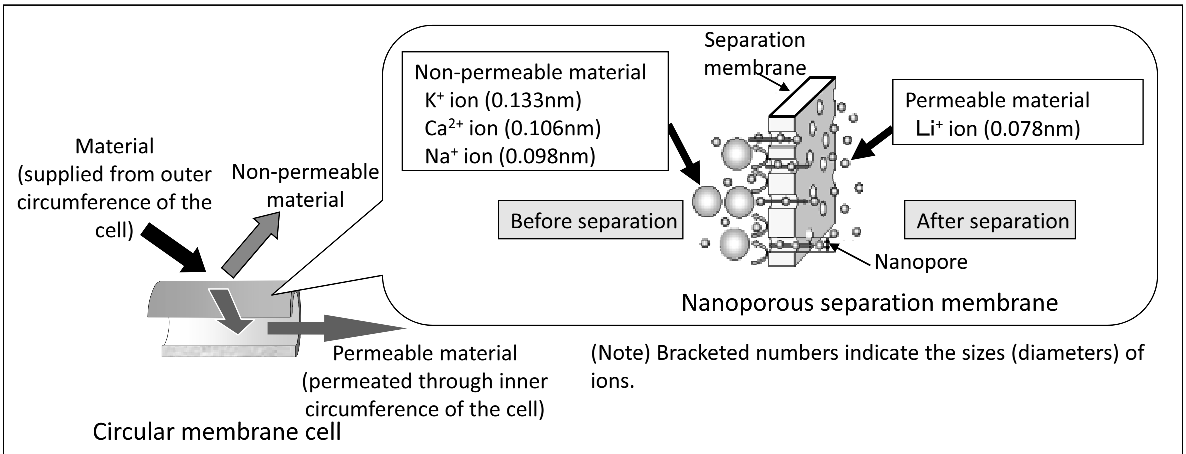


Figure 9: Concept of a nanoporous structure-based lithium-ion separation membrane and cell

Prepared by STFC

be used for the negative electrode, and a catalyzer may be used to create an air electrode making use of oxygen in the air (for the positive electrode). However, current research and development efforts have not yet solved some basic issues including: performance improvement of the catalyzer for the air electrode, improvement of charge-discharge cycle characteristics, substantial improvement of low-heat characteristics, precipitation control of dendrite (a bark-like material that forms in the electrolyte and on the electrode surfaces), and the understanding of the charging mechanism.[35] Furthermore, if a catalyzer contains rare metals, it is essential to reduce the amount of the metals. In contrast, a multivalent cation battery is promising for creating high energy density because it generates electricity by moving cation ions (that have multiple charges) and enables multiple energy transfer in a battery of the same size as a metallic-lithium-based battery. Oxides and sulfides may be used for the positive electrode, and magnesium, calcium, and aluminum may be used for the negative electrode. However, there are also some basic issues to be solved for this type of battery, including the creation of an optimum battery structure and the improvement of charge-discharge cycle characteristics.[5]

6 Conclusion

Japan has been maintaining its superiority in lithium secondary battery technology. However, in recent years, the share of South Korean and Chinese companies in global sales has been dramatically increasing. It is almost certain that demand for lithium raw materials will drastically increase, considering the rapidly increasing popularity of vehicles equipped with a secondary battery and the related rise in demand for lithium (just to cover demand for automobiles). It is essential for Japanese companies to stably acquire lithium raw materials in order to continue to be a leader in the world. It is necessary for both the government and the private sector to understand the resource policies of producing countries and strengthen efforts, in a planned manner, to acquire lithium resources. While carefully monitoring the resource policies of producing countries, trends in oligopolistic producing companies, and changes in prices of lithium raw materials, it is desirable to reduce excessive dependence on certain producing countries and have a variety of trading partners in order to prevent risks.

In the medium term, it is also important to research and develop technology to reduce the time required to produce lithium resources from brine water, and in the long term, it is essential to develop technology to recover metallic lithium from seawater and to develop separation membrane technology. If such technology to recover metallic lithium from seawater becomes practical, it will be possible to secure lithium raw materials without being affected by the resource nationalism of producing countries. It is also important to research and develop metallic-lithium-free secondary batteries.

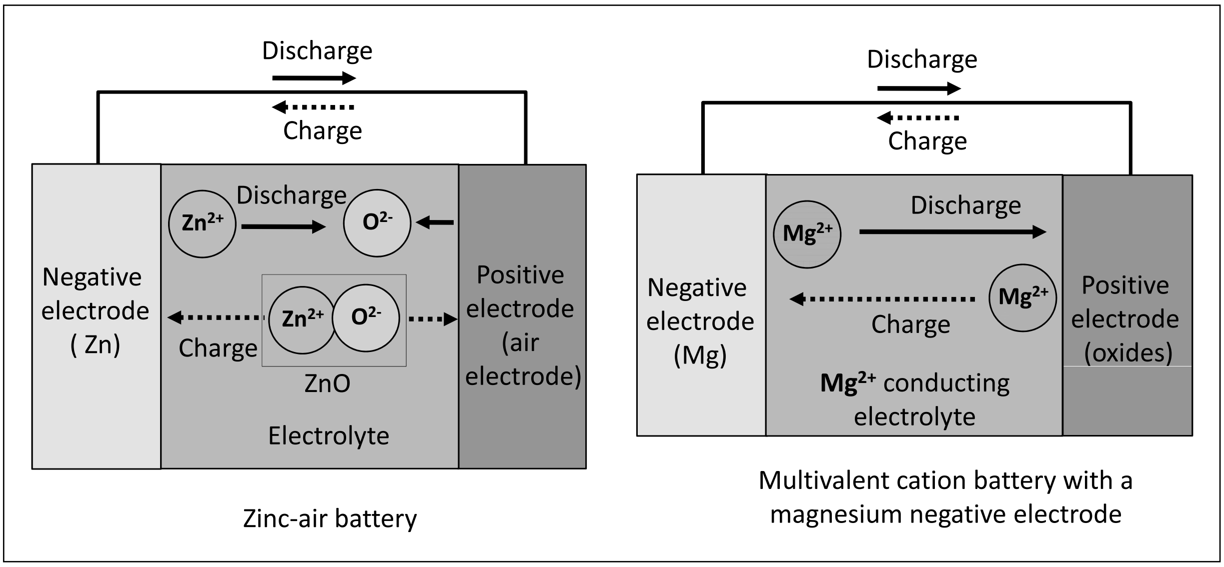


Figure 10: Electricity generation mechanisms of a zinc-air battery and of a multivalent cation battery with a magnesium negative electrode

Reconstructed by STFC based on a figure in Reference[5]

References

[1] Hiroshi Kawamoto, "Trends of R&D on Materials for High-power and Large-capacity Lithium-ion Batteries for Vehicles Applications", Science & Technology Trends (No. 106), January 2010

[2] Summary of 2010 Mid-Year CEO Speech, Honda Motor Co., Ltd., http://www.honda.co.jp/news/2010/c100720a.html

[3] "Next-Generation Vehicle Strategy 2010", Ministry of Economy, Trade and Industry, April 12, 2010

[4] Keisuke Ogawa, "EVs and HEVs Make up 50% of New Car Sales by 2020", Nikkei Automotive Technology, 2010: http://techon.nikkeibp.co.jp/article/TOPCOL/20100413/181819/?ST=NAT

[5] "2008 Roadmap for the Development of Next Generation Automotive Battery Technology, NEDO": http://app3.infoc.nedo.go.jp/informations/koubo/other/FA/nedoothernews.2009-05-29.2374124845/30ed30fc30de30c389e38aacP_516c958b7248518d65398a027248_.pdf

[6] Yukinori Abe, Katsuhisa Ono, "Lithium Supply & Market 2009 Report (part 1)", JOGMEC Mineral Resources Report, Volume 09-02, 2009

[7] Katsuhisa Ono, "Lithium Resources and Demand—Lithium Supply & Markets Conference 2009 (LSM'09) Report—," JOGMEC Current Topics, Volume 09-21, 2009

[8] Hiroshi Kawamoto,"Japan's Policies to Be Adopted on Rare Metal Resources", Science & Technology Trends (No. 79), July 2007

[9] Tetsuro Urabe, Lecture at NISTEP, "Development of Seabed Rare Mineral Resources and Japan's Strategy", 2007

[10] USGS Mineral Commodity Summaries 2010

[11] Yukinori Abe, "Rare Metal Series 2010—Current Status of Lithium Resources—", JOGMEC Mineral Resources Report, 2010

[12] Katsuhisa Ono, "Trends in Chile's Lithium Production and Exports in 2009 and its Current Legal Systems Surrounding Lithium", JOGMEC Current Topics, Volume 10-21, 2010

[13] "Mineral Resources Material Flow 2009", JOGMEC: http://www.jogmec.go.jp/mric_web/jouhou/material/2009/mineral_resource.pdf

[14] "United Nations Commodity Trade Statistics Database", http://comtrade.un.org/

[15] Maki Sekimoto, "Demand and Supply of Rare Earth Elements, Indium, Gallium, and Lithium", JOGMEC: http://www.jogmec.go.jp/mric_web/koenkai/090304/briefing_090304_3.pdf

[16] "Worldwide Competition for Lithium", Nihon Keizai Shimbun, July 15, 2010

[17] "Controversy over Chile's Lithium Mining Restrictions", Metal Research Bureau News, August 12, 2010: http://mrb.ne.jp/newscolumn/3008-1.html

[18] "China Nonferrous Metals Industry Association sets up a lithium industry branch", Metal Research Bureau News, August 27, 2010

[19] Metal Research Bureau News, April 26, 2010: http://mrb.ne.jp/newscolumn/3096-1.html

[20] "South Korea beats Japan in acquiring the right to develop lithium in Bolivia—South Korea's resource strategy succeeds with the ability to execute—", Metal Research Bureau News, August 28, 2010

[21] Korea JoongAng Daily, "Korea and Bolivia establishes a joint research group to develop lithium": http://japanese.joins.com/article/article.php?aid=132479

[22] "Basic Energy Plan", Ministry of Economy, Trade and Industry: http://www.meti.go.jp/press/20100618004/20100618004-2.pdf

[23] "Lithium development in Bolivia—Japan takes the lead—", Nihon Keizai Shimbun, November 10, 2010

[24] "Japan works with Mongolia to develop lithium—The government aims to secure stable procurement for large-capacity batteries—", Nihon Keizai Shimbun (evening edition), December 1, 2010

[25] "JOGMEC Enters into Joint Exploration Agreement for Lithium in Nevada", U.S., JOGMEC News Release, June 11, 2010: http://www.jogmec.go.jp/news/release/docs/2010/pressrelease_100611.pdf

[26] "Galaxy Resources Limited (ASX: GXY) signs an off-take agreement with Mitsubishi Corporation for lithium carbonate production", JOGMEC News Flash: http://www.jogmec.go.jp/mric_web/news_flash/10

—08.html#19
[27] “Toyota Tsusho participates in a joint venture to develop lithium resources in Salar de Olaroz in Argentina”, Toyota Tsusho Corporation, News Release: http://www.toyota-tsusho.com/data/current/detailobj-794-datafile.pdf
[28] “Itochu Corporation invests in a U.S.-based lithium resources development company to secure stable procurement”: http://eco.nikkeibp.co.jp/article/news/20100706/104167/
[29] “Mitsui signs an exclusive lithium distributorship agreement with Canada Lithium Corp, aiming to secure stable procurement of major materials for secondary batteries for eco-friendly cars”, Mitsui & Co., Ltd., News Release: http://www.mitsui.co.jp/release/2009/1189710_3576.html
[30] Yukinori Abe, “Current status of Lithium Production from Brine”, JOGMEC: http://www.jogmec.go.jp/mric_web/koenkai/090730/briefing_090730_6.pdf
[31] “Science and the Industry of Seawater”, Tokai University Press, 1994
[32] Kazuharu Yoshizuka, “Practical Recovery Technology of Lithium from Seawater”, Conference on Material from Advanced Science and Technology for Utilization of Ocean Energy (21st Century COE Program): http://chemeng.env.kitakyu-u.ac.jp/research/Lithium.pdf
[33] “Extracting lithium from Seawater: Full-fledged Operation at a Plant in Saga Prefecture”: http://www.47news.jp/CN/200404/CN2004041701000022.html
[34] Yuji Iwamoto, Hiroshi Kawamoto, “Trends in Research and Development of Nanoporous Ceramic Separation Membranes”, Science & Technology Trends (No. 95), February 2009
[35] “Development of a New-type Lithium-Air Battery with Large Capacity”, National Institute of Advanced Industrial Science and Technology, 2009: http://www.aist.go.jp/aist_j/press_release/pr2009/pr20090224/pr20090224.html

Profile

Hiroshi KAWAMOTO
Affiliate fellow
Science & Technology Foresight Center
http://www.nistep.go.jp/index-j.html

Doctor of engineering, and Fellow of Japan Society of Mechanical Engineers. At Toyota, Dr. Kawamoto took charge of the mechanical design and evaluation of automobile components at the design stage. After leaving Toyota, he was engaged in METI-related projects (R&D on fine ceramics, etc.) at the Japan Fine Ceramics Center. He was a fellow at the Science & Technology Foresight Center for three years, starting in 2006. Now, he is a part-time professor at Meijo University. He specializes in strength-design and reliability-evaluation for structural materials and components.

Wakana TAMAKI
Researcher
Nanotechnology and Materials Research Unit
Science & Technology Foresight Center

Ms. Tamaki is from Okinawa prefecture. After receiving her master’s degree, working at a company, and conducting research at a university, she became a researcher at the Science & Technology Foresight Center. As a teenager, Ms. Tamaki became very interested in the improper treatment of used automobiles in her local community. Since she was a college student, she has been engaged in statistical research on the recycling of iron and other metals. She has been fascinated by some exciting materials in her research and now she hopes to publicize those intriguing results without failing to express such fascination.

(Original Japanese version: published in December 2010)